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Endogenous time-dependent rules and the costs of disinflation with imperfect credibility

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Endogenous Time-Dependent Rules and the Costs of Disinflation with Imperfect Credibility*

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Abstract

This paper examines the output effects of monetary disinflation in a model with endogenous time-dependent pricing rules and imperfect credibility of the disinflation policy. We find that these features interact to generate an additional effect on top

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of the ones obtained with either endogenous time-dependent rules (Bonomo and Carvalho, 2003) or imperfect credibility (Ball, 1995) in isolation. This results in higher output costs of monetary disinflation.

JEL classification: E31;E52

1 Introduction

It is largely believed that nominal rigidities are important to understand the business cycle, and, in particular, why it is so costly to disinflate. Most papers concerned with those issues choose either deterministic (Taylor, 1979, 1980) or stochastic (Calvo, 1983) time-dependent pricing rules (e.g. Ball, 1994, 1995 use Taylor-type; Yun, 1996, Clarida, Gali and Gertler, 1999 and Woodford, 2003 use Calvo-type)[1]. Nonetheless, a common feature of the vast majority of these models is the use of invariant price setting rules[2]. In particular, the contract length in Taylor-type models and the average frequency of price adjustments in Calvo-type models are not responsive to changes in the economic environment. This way of proceeding is clearly inappropriate when there are transformations in the environment, as it is the case when policy rules are changed[3]. When monetary authorities launch a disinflationary program they usually claim that the monetary rule

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[1] More recently, some papers which use variations of time-dependent rules are Calvo, Celasun and Kumhof (2003), who assume that firms choose (linear) price paths rather than levels and Mankiw and Reis (2002), who postulate Calvo-style randomization with respect to the arrival of information, rather than the opportunity to adjust prices.

[2] One exception is Kiley (2000), who follows Romer (1990) in endogeneizing the frequency of price adjustment in Calvo-type rules to study the business cycle. However, these two papers do not address the issue of optimality of such rules.

[3] Ireland (1997), motivated by this shortcoming of exogenous time-dependent rules, uses Ball and Mankiw's (1994) partially state-dependent rules to study how disinflation costs are related to the initial inflation rate.

will be modified.

Recently, Bonomo and Carvalho (2003) studied perfectly credible monetary disinflations in an economy where price setters use endogenous time-dependent rules. In order to make time-dependent rules optimal, they assume that adjustment and information costs cannot be dissociated[4]. They develop a methodology for aggregating pricing rules out of steady-state in order to evaluate aggregate output effects of monetary disinflation. The outcome is that endogeneity of time-dependent rules increases moderately the output costs of disinflation.

In this paper we examine the output effects of monetary disinflation under imperfect credibility in a model in which firms follow endogenous time-dependent rules. Credibility has both a direct and an indirect effect on prices. The direct effect is through the expectation of the optimal price during a given contract length. Ball (1995) showed, in a model with exogenous time-dependent rules, that because of this direct effect, the costs of disinflation increase when imperfect credibility and staggered price-setting are combined. The indirect effect arises in our model with endogenous rules because the change in contract length also affects the price chosen. With abrupt changes in the environment, as it happens with the announcement of a new disinflation policy, this effect is not second order.

Endogeneity of time-dependent rules increases the costs of imperfectly credible disin-

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[4]Conlon and Liu (1997) also assume that paying one lump-sum cost allows a firm to change both its price and product mix.

flation under two metrics. First, it increases the recession when the stabilization is never abandoned. Second, it increases the average costs of disinflation, evaluated by averaging each possible path generated by a given abandonment time according to its likelihood. The intuition underlying the result is simple. Under imperfect credibility, individual prices are set at higher levels (when compared to the full credibility case) because there is some probability that the stabilization will be abandoned before the next adjustment. With endogenous rules, the increase in contract length, which takes place while the stabilization is maintained, raises the probability of abandonment before the next adjustment, reinforcing this effect. We find that these features interact to generate an additional effect on top of the ones obtained with either endogenous time-dependent rules (Bonomo and Carvalho, 2003) or imperfect credibility (Ball, 1995) in isolation.

Almeida and Bonomo (2002) use endogenous state-dependent rules to examine output costs of monetary disinflation. In contrast with our results, they found that disinflation costs are smaller when computed with endogenous rules. This confirms the insight provided by Caplin and Spulber's (1987) neutrality result that the type of nominal rigidity matters, even for qualitative results. They also treat briefly the case of imperfect credibility. In the context of state-dependent rules, credibility simply affects the magnitude of the pricing rule change, with less credible policies causing less changes in pricing policies. They compute the effect of a disinflation that is carried out without reneging, for various degrees of credibility, but they do not evaluate average results, as we do here.

The remaining part of the paper is organized as follows. In section 2 we present the basic setting. Section 3 solves for optimal pricing rules under imperfectly credible disinflation and presents a methodology for aggregating individual pricing rules out of the steady-state. Section 4 reports the aggregate effects obtained in our simulations and the last section concludes.

2   The Model

We build on the static model results of Blanchard and Kiyotaki (1987), and Ball and Romer (1989). Starting from the specification of preferences, endowments and technology, these models derive individual optimal price equations at each moment as a function of aggregate demand (Ball and Romer) or directly as a function of the money supply and price level (Blanchard and Kiyotaki). In order to generate individual uncertainty about the optimal individual price, we add an idiosyncratic shock process to the optimal price equation obtained in those models. These shocks are permanent and thus, together with the money supply process and adjustment/information costs, generate intertemporal links which make the model dynamic[5].

Our economy is populated by an infinite collection of identical (in all aspects other than the timing of adjustments and realization of idiosyncratic shocks) imperfectly competitive

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[5]Having a dynamic macro model with intertemporal consumption and investment decisions would complicate the model without affecting the main insights.

firms indexed in the interval $[0, 1]$. We assume that the optimal level of the individual

relative price, in the absence of frictions, is given by:

$$p_i^* - p = \theta y + e_i \tag{1}$$

where p_i^* is the individual frictionless optimal price, p is the average level of prices,

y is aggregate demand and e_i is an idiosyncratic shock to the optimal price level (all

variables are in log)[6]. We assume that for each i, e_i follows a driftless Brownian motion

with coefficient of diffusion σ and that those individual processes $e_i's$ are independent of

each other. Since firms are identical (although they can have different prices and supply

different quantities), for simplicity we evaluate p at any time t according to:

$$p(t) = \int_0^1 x_i(t) di$$

where $x_i(t)$ is the price charged by the firm i at time t.

Nominal aggregate demand is given by the quantity of money:

$$y + p = m$$

Substituting the above equation into equation (1) yields[7]:

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[6] Equation 1 states that the relative optimal price depends on aggregate demand and on shocks specific

to the firm. It can be derived from utility maximization in a yeoman farmer economy, as in Ball and

Romer (1989).

[7] This equation can also be derived directly from other specifications, such as Blanchard and Kiyotaki

$$p_i^* = \theta m + (1 - \theta)p + e_i \tag{2}$$

If there were no costs to adjust prices and/or obtain information about the frictionless optimal price level, each firm would choose $x_i(t) = p_i^*(t)$ and the resulting aggregate price level would be $p(t) = m(t)$. Thus aggregate output and individual prices would be given by $y(t) = 0$ and $x_i(t) = m(t) + e_i(t)$, respectively.

We assume that the firm can neither observe the stochastic components of p_i^* nor adjust its price based on the known components of p_i^* without paying a lump-sum cost F. On the other hand, to let the price drift away from the optimal entails expected profit losses, which flow at rate $E_{t_0}(x_i(t) - p_i^*(t))^2$, where t_0 is the last time of observation and adjustment and E_{t_0} is the expectation conditioned on the information available at that time[8]. Time is discounted at a constant rate ρ.

Given the stochastic process for the optimal price, each price setter solves for the optimal pricing rule. The cost function after paying the adjustment/information gathering cost at a certain time t_0, can be written in the following way:

$$V = \min_{\{t_j\},\{x_i(t_j)\}} E_{t_0} \sum_{j=0}^{\infty} e^{-\rho(t_j - t_0)} \left[\int_0^{t_{j+1} - t_j} e^{-\rho s} \left(x_i(t_j) - p_i^*(t_j + s) \right)^2 ds + F \right] \tag{3}$$

(1987), where real balances enter the utility function.

[8] Observe that this form corresponds to a second order Taylor approximation to the expected profit loss for having a price different from the optimal one whenever the second derivative of the profit function is constant.

where t_j is a time of adjustment/information gathering and $x_i(t_j)$ is the price chosen at time t_j.

In analyzing disinflations we start from an inflationary steady state characterized by a constant rate of inflation. Let μ be the constant rate of money growth. The evolution of the frictionless optimal level in steady state will be given by the following equation:

$$dp_i^* = \mu dt + \sigma dw_i \tag{4}$$

In this case, it can be shown that the optimal adjustment interval τ^* is defined implicitly by the following equation (see Bonomo and Carvalho, 2003 for details):

$$\rho F + \rho \frac{\int_0^{\tau^*} \left(\left(\mu \left[\frac{1}{\rho} - \frac{e^{-\rho \tau^*}}{1 - e^{-\rho \tau^*}} \tau^* \right] - \mu s \right)^2 + \sigma^2 s \right) ds + e^{-\rho \tau^*} F}{1 - e^{\rho \tau^*}} \tag{5}$$

$$= \left[\mu \left[\frac{1}{\rho} - \frac{e^{-\rho \tau^*}}{1 - e^{-\rho \tau^*}} \tau^* \right] - \mu \tau^* \right]^2 + \sigma^2 \tau^*$$

Based on the above equation, one can demonstrate that the optimal contract length is decreasing in $|\mu|$ and σ, increasing in F and is not affected by the degree of strategic complementarity, $1 - \theta$[9].

In our simulations, we set $\sigma = 3\%$ and calibrate F in such a way that with $\mu = 3\%$, $\sigma = 3\%$ and $\rho = 2.5\%$ a year, a firm chooses to collect information and adjust its price once a year. As a result we set $F = 0.000595$. This frequency of adjustments is consistent with

[9]This is because it only affects the level of variables $p(t)$ and $p_i^*(t)$, but not their growth rates. This ceases to be true out of the steady state.

the findings of Carlton (1986) and Blinder et al. (1998) that in the American economy the median firm adjusts its price approximately once a year. This configuration of parameters also generates plausible adjustment intervals for high inflation environments[10].

3 Optimal Pricing Rules under Imperfectly Credible Disinflation and Aggregation

In this section we derive optimal pricing rules during disinflation. In general this requires solving both an optimization and an aggregation problem simultaneously. This is because the optimal rule depends on the expected path for the aggregate price level and the path for the aggregate price results from the aggregation of the individual pricing rules. In the absence of strategic complementarities ($\theta = 1$) these problems can be solved separately.

We simplify the analysis by assuming away strategic complementarities, which allows us to solve the problem sequentially.

A disinflation path for $m(t)$ is announced at $t = 0$. Although the quantitative equation. does not take into account explicitly the effect of inflation reduction, one can interpret the variable m as the nominal aggregate demand, and assume that the Monetary Authorities set the trajectory of the money supply that corresponds to our path for nominal aggregate demand[11]. Under this interpretation, for example if the variable m is halted,

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[10] See Bonomo and Carvalho (2003).

[11] This strategy for modelling monetary disinflations is also followed by Mankiw and Reis (2002).

money supply is increased by an amount just enough to satisfy the higher money demand due to lower inflation expectations and maintain the nominal aggregate demand constant.

The problem of a firm adjusting at $t > 0$ can be characterized by the following Bellman equation:

$$V(t) = \min_{x_i(t),\tau(t)} E_t \left[\int_t^{t+\tau(t)} e^{-\rho(s-t)} [x_i(t) - p_i^*(s)]^2 \, ds + e^{-\rho\tau(t)} F + e^{-\rho\tau(t)} V(t + \tau(t)) \right]$$

The first order conditions are:

$$x_i(t) = \frac{\rho}{1 - e^{-\rho\tau(t)}} \int_t^{t+\tau(t)} E_t p_i^*(s) e^{-\rho(s-t)} ds \tag{7}$$

$$E_t \left\{ [x_i(t) - p_i^*(t + \tau(t))]^2 - \rho F - \rho V(t + \tau(t)) + V'(t + \tau(t)) \right\} = 0 \tag{8}$$

The problem above can be solved recursively, assuming that after a long time the economy will reach a new steady state. Thus, for t large enough, $V(t) = V_{\mu'}$, where $V_{\mu'}$ is the value function for the new steady state (money growth rate μ').

This formulation encompasses imperfect credibility in general, which enters the problem through the expectations operator. Economic agents in general do not fully believe that a change in the monetary policy will last forever. It is not true, either, that they are absolutely sure the new policy will be abandoned immediately. We therefore model imperfect credibility as a conjecture that in each finite time interval there is a positive

probability that the monetary authorities will renege. For simplicity, we assume that the probability of reneging at the next time interval is always the same. Thus, we model the rate of growth of the money supply after stabilization as a Poisson process with constant arrival rate h[12]. Once the new policy is abandoned, the agents believe that the old policy will be kept forever[13].

Specifically, after the stabilization policy is launched, the process for the money supply is given by:

$$dm = (0 + \mu 1_{\{N_t \geq 1\}})dt$$

where N is a Poisson counting process with constant arrival rate h, and $1_{\{.\}}$ is the indicator function. Then, the drift of the money supply will change from zero to μ when an arrival occurs.

The parameter h can be interpreted as a measure of credibility. The extreme cases of perfect and no credibility are associated with zero and infinity values for h, respectively. Imperfect credibility is represented by strictly positive finite values, and the higher is h, the lower the degree of credibility. Observe that the probability the monetary authorities will not renege until T periods after the stabilization is given by e^{-hT}. Thus, if $h = 0.5$, the probability that the stabilization will continue after one year is 61%.

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[12] This is the same approach as in Ball (1995) and Almeida and Bonomo (2002).

[13] For simplicity, we specify a constant money supply growth rate after the stabilization flaw. To choose this inflation rate to be the same as the pre-stabilization level is appealing, if one believes that certain structural features of the economy determine money supply growth.

In this case the problem of a firm while the stabilization has not been reneged on may be written as:

$$V_h = \min_{x_i(t),\tau(t)} e^{-h\tau} \left\{ E_t \int_0^\tau [x_i(t) - e_i(t+s)]^2 e^{-\rho s} ds + F e^{-\rho\tau} + V_h e^{-\rho\tau} \right\} + \qquad (9)$$

$$\int_0^\tau \left\{ \begin{array}{c} E_t \int_0^r [x_i(t) - e_i(t+s)]^2 e^{-\rho s} ds + \\ \\ E_t \int_r^\tau [x_i(t) - \mu(s-r) - e_i(t+s)]^2 e^{-\rho s} ds + e^{-\rho\tau} F + e^{-\rho\tau} V_\mu \end{array} \right\} h e^{-hr} dr$$

where V_μ is the cost function for the inflationary steady state problem. The first line of the expression refers to the probability that the stabilization will be kept during the next contract multiplied by the cost in this case. The second line is the cost if abandonment occurs at time $t + r$ (between curly brackets) weighted by the likelihood that it would occur at that time. Observe that if abandonment occurs at a time before the subsequent contract, the same will be reset under conditions identical to the inflationary steady state. This results in the cost function V_μ[14].

The first order conditions are derived in a straightforward way:

$$x_i(t) = \frac{\rho}{1 - e^{-\rho\tau}} \int_0^\tau \left[\mu s - \frac{\mu}{h} \left(1 - e^{-hs} \right) \right] e^{-\rho s} ds + e_i(t) \qquad (10)$$

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[14] One implicit assumption here is that firms do not reevaluate their contracts before planned. This assumption is relaxed in Bonomo and Carvalho (2003), who conclude that the changes in the results can be important for high but not for low inflation environments. We conjecture that a similar conclusion obtains under imperfect credibility, for the same reasons outlined in that paper.

$$E_t \left[x_i(t) - e_i\left(t + \tau\right)\right]^2 + he^{-h\tau}\left(V_\mu - V_h\right) - \qquad (11)$$

$$\rho\left(e^{-h\tau}V_h + \left(1 - e^{-h\tau}\right)V_\mu + F\right) + \int_0^\tau \left[\mu\left(\tau - r\right)\right]^2 he^{-hr}dr = 0$$

From 10, 11 and 9 we obtain a nonlinear equation in τ, which can be solved numerically.

Figure 1 shows the contract length function for different credibility levels. The case $h = 0$ corresponds to perfect credibility, while $h = \infty$ corresponds to the case where stabilization is abandoned immediately with probability one. As expected, the higher h is (the lower the credibility level), the smaller the increase in contract length is.

In the next subsection we explain briefly the methodology for aggregation of endogenous time-dependent rules out of steady-states.

3.1 Aggregation Methodology

With endogenous rules in a changing environment, the contract length changes through time. As a consequence, the distribution of price adjustments will be changing accordingly, and aggregation requires monitoring the evolution of this distribution. For simplicity, we assume that the initial (steady-state) distribution is uniform, which is the invariant distribution in the inflationary steady state. However, the methodology could be applied to any initial distribution.

Let $g(.)$ be the function of time which gives the next adjustment time. Then $g(t) = t + \tau(t)$. During credible disinflations $g(.)$ tends to be nondecreasing, since firms tend to

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choose longer contract lengths [15]. In the case of imperfect credibility, $g(.)$ decreases at the moment the disinflation policy is abandoned.

In order to calculate the price level at a time after the announcement, we use the function $g(.)$ to relate the measure of firms which set their actual prices at a specific time u to the measure of firms at times before u that would have their next adjustment at u (those times are $g^{-1}(u)$). Let $Z(t)$ be the correspondence that assigns to t the set of times when the current prices were last adjusted. Formally:

$$Z(t) = \{s : s \leq t \text{ and } g(s) > t\}$$

Let $g^{-1}(S)$ be the inverse image of the set S under g. Then, $g^{-1}(Z(t))$ is the set of adjustment times for which the next adjustment would be in $Z(t)$. To evaluate the average price at t we need to know the probability measure v of the firms which adjust at subsets of $Z(t)$. We can easily relate this measure to the measure φ in subsets $g^{-1}(Z(t))$, since v is the image measure of φ under g. Then we have:

$$p(t) = \int_{Z(t)} x(s)v(ds) = \int_{g^{-1}(Z(t))} x(g(s))\varphi(ds)$$

We apply the above formula recursively by relating distributions and adjustment time sets during disinflation to distributions and sets at preceding times. We proceed this way until we arrive at a set $g^{-n}(Z(t))$ such that the measure of firms adjusting at the subset of times of this set corresponds to the uniform distribution of the inflationary steady state.

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[15] See Bonomo and Carvalho (2003).

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Since we assumed away strategic complementarities, we first obtain the $g()$ function from the optimal pricing rules presented in the previous section and then aggregate individual prices as described above.

4   Results

In Figure 2 we present the output effects of a disinflation which is maintained forever, for different degrees of credibility. As expected, the lower the degree of credibility, the larger the recession generated. It is clear that endogeneity of pricing rules reinforces this result. This happens because contract lengths are increased after disinflation. For $h = 0$, this corresponds to the perfect credibility result of Bonomo and Carvalho (2003). In this case, as noticed in that paper, if inflation is reduced to zero and there are no strategic complementarities, the output costs of disinflation are the same with endogenous or exogenous rules. The reason is that every firm which adjusts after disinflation is announced knows that the aggregate component of their optimal price will be constant. Then the length of the contract will not matter for the non-idiosyncratic part of their price. With imperfect credibility this result is not true anymore, since there is some probability that the central bank will abandon the stabilization before the next adjustment time, in which case inflation will return. If the price is fixed for a longer interval, the probability is higher. Therefore prices are set at higher levels and the recession is larger.

However, one may argue that this case corresponds to an event of zero probability in

the prior assessment of firms. A more complete analysis has to take into consideration what happens during trajectories where stabilization is reneged. In this case, the output path will depend on the moment of abandonment. There is a recession before stabilization is abandoned that turns into a boom just afterwards. Before stabilization is abandoned, firms set prices higher than in the case of perfect credibility because they attribute some probability that the monetary authorities will renege before their next price adjustment. This generates a larger recession than in the case of perfect credibility. When stabilization is abandoned the money stock starts growing and so does output, since some past prices were set attributing a positive probability that the stabilization would be maintained. This is a reverse hangover effect. Thus, if stabilization is abandoned right after the announcement, both the recession and the boom are small, since the hangover effect is active for little time and the reverse hangover effect has little time to build up. More sizable recessions and booms happen when stabilization lasts longer. This is illustrated in Figure 3.

Note that there are periods in which no price adjustments take place, due to the change in contract lengths. These will be compensated by periods in which a larger measure of firms adjust. This change in the distribution of adjustment times generates aggregate cycles which are not present in the case of invariant rules.

One possible way of summarizing this effects is by averaging each individual path according to its likelihood. Figure 4 shows the average output path for both invariant

and endogenous rules for a given level of credibility ($h = 0.5$). The recession is more severe when rules are endogenous. Because the contract length gets longer, the possibility of abandonment leads to price setting at higher levels when compared to the exogenous rules case. In the case of endogenous rules, we can also notice that after some time output oscillates between boom and recession. This is because for some realizations of the Poisson counting process, there will be holes in the distribution of adjustment times. Averaging across all realizations yields the results depicted.

Figure 5 depicts the average output path for various degrees of credibility. The effect is non-monotonic in the degree of credibility. The recession increases when the degree of credibility increases, starting from zero, decreasing after some point. At the extreme case of no credibility ($h = \infty$) there is no recession, since the stabilization is abandoned instantaneously and the inflationary steady state is maintained.

One could also imagine a situation in which a monetary authority that is really serious about disinflation ($h = 0$) faces firms which have prior beliefs about the "true type" of the monetary authority (summarized by a common prior over h) and choose optimal pricing rules accordingly. As stabilization is maintained, agents update their beliefs about the type of monetary authority they face and this should attenuate the recession trough time. Suppose, for example, that the firms' priors attribute a high likelihood that $h = 0.5$. Then, initially the recession should be like the one caused when the monetary authority continues to disinflate despite having low credibility, on the $h = 0.5$ curve depicted in

Figure 2. As time passes, credibility builds gradually and thus output should approach the path represented by the $h = 0$ case in Figure 2.

5   Conclusion

One of the main methodological weaknesses in the literature which relates nominal rigidities and costs of disinflation is that pricing rules are invariant to policy regimes. This paper evaluates the effect of imperfect credibility of the disinflation announcement on the output costs it generates in a model with endogenous time-dependent pricing rules. We rationalized fixed price time-dependent rules as optimal rules, presented the solution for the optimal rule in the case of an imperfectly credible disinflation and used a suitable methodology for aggregating pricing rules under non-steady state conditions.

The results show that the endogeneity of rules matters for the assessment of the role of credibility in disinflation processes. We find that these features interact to generate an additional effect on top of the ones obtained with either endogenous time-dependent rules (Bonomo and Carvalho, 2003) or imperfect credibility (Ball, 1995) in isolation. This results in higher output costs of monetary disinflation.

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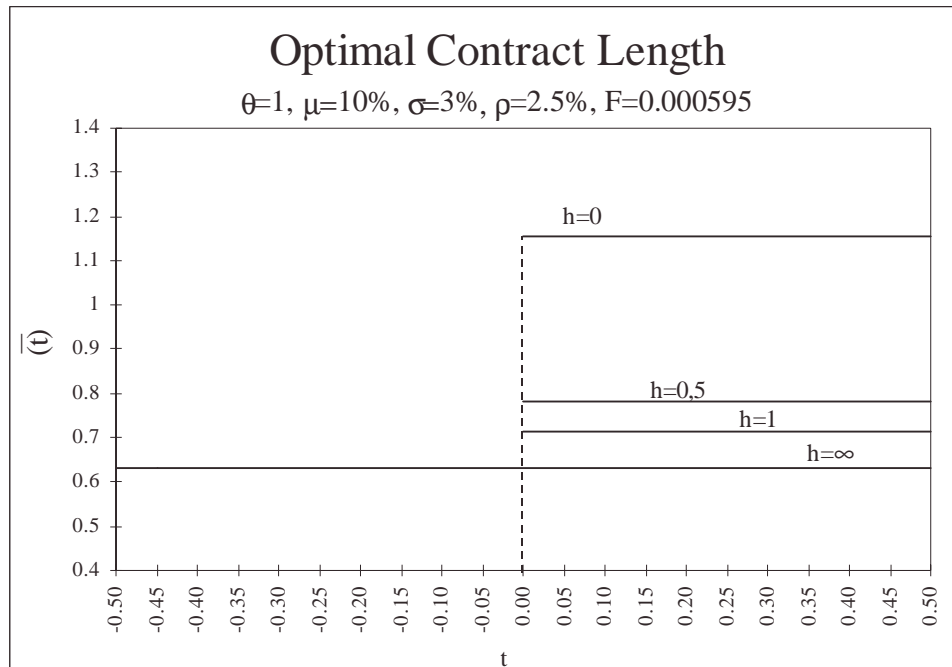[22] Yun, T. (1996) "Nominal price rigidity, money supply endogeneity, and business cycles," Journal of Monetary Economics 37: 345-370.
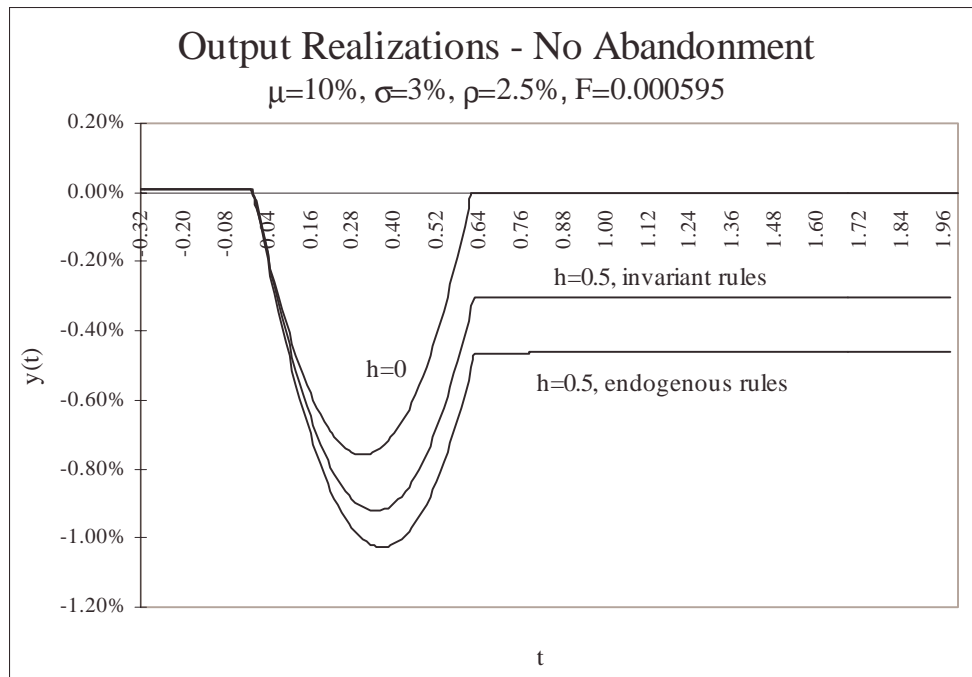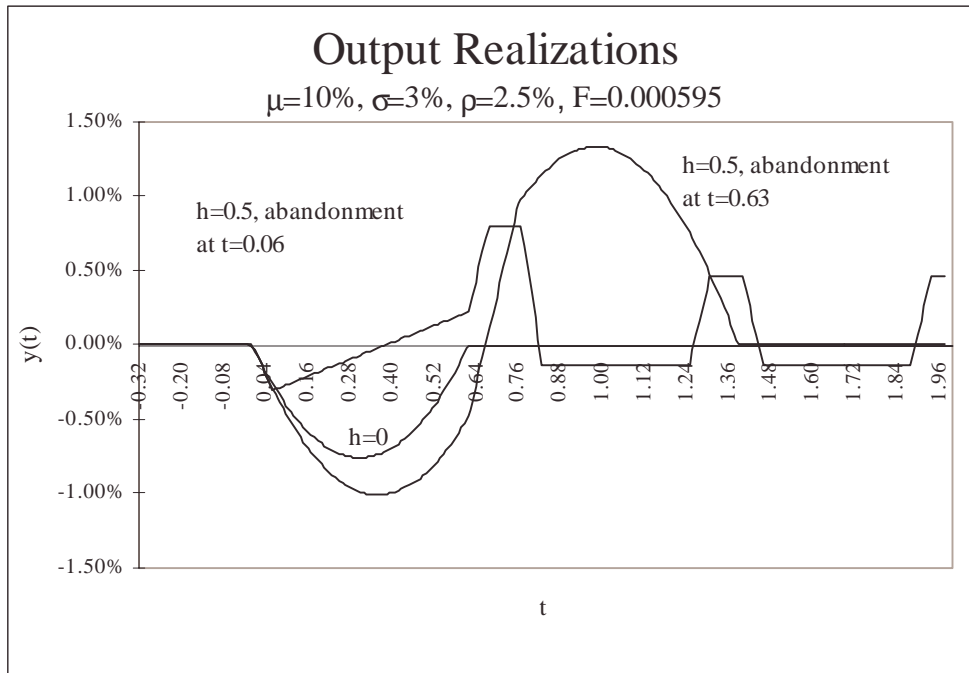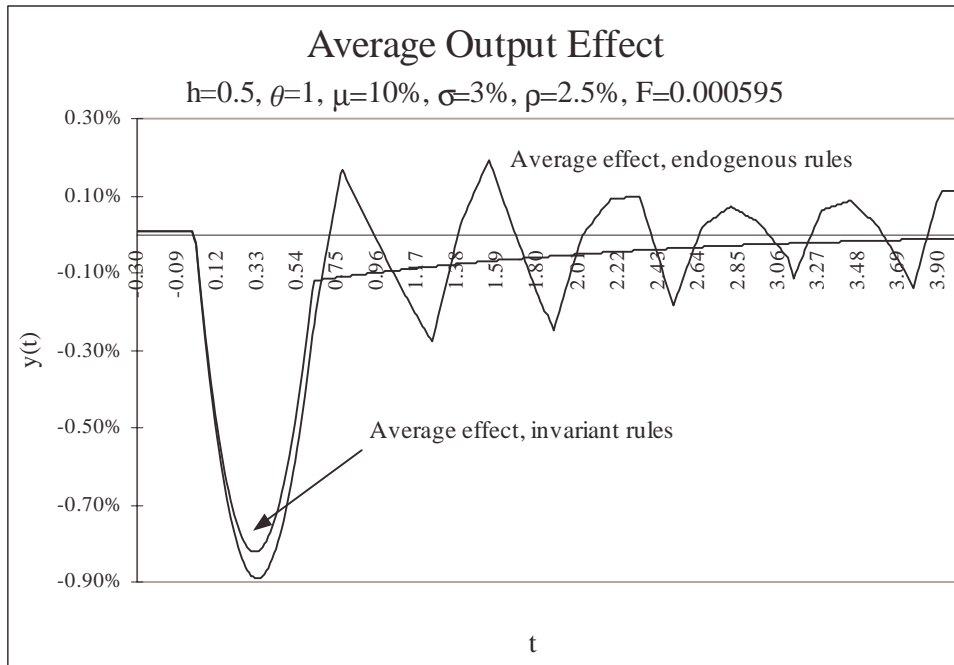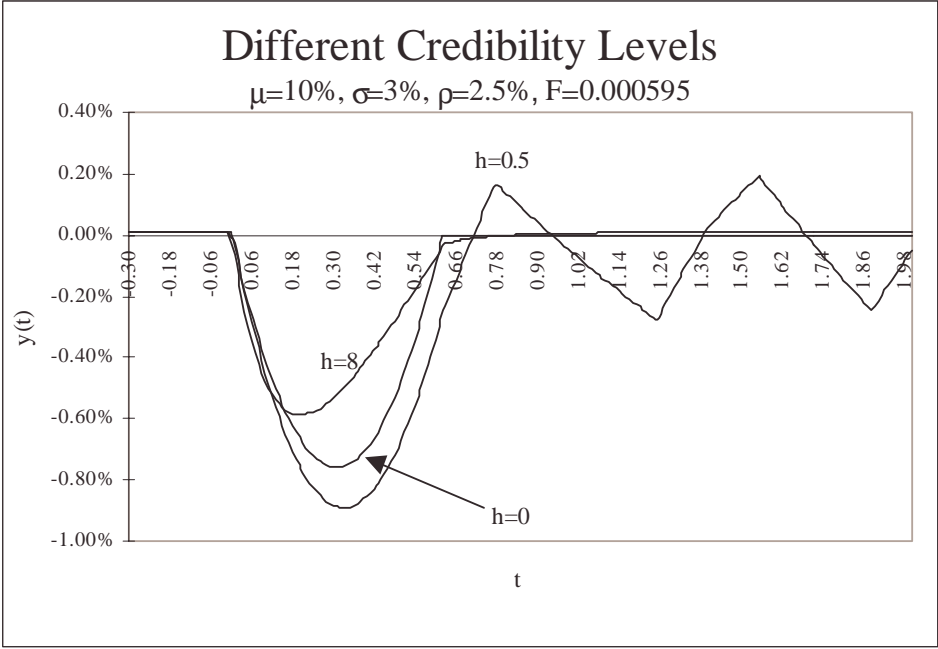
Figure 1:

Figure 2:

Figure 3:

Figure 4:

Figure 5:

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